Improved Doppler Radar/Satellite Data Assimilation

Allen Zhao

Marine Meteorological Division, Naval Research Laboratory
7 Grace Hopper Ave, Mail Stop II, Monterey, CA 93943-5502
Phone: (831) 656-4700 fax: (831) 656-4769 email: Allen.Zhao@nrlmry.navy.mil

LONG-TERM GOALS

Our goal is to develop a short-term high-resolution data assimilation capability that can provide the Navy with improved analyses and forecasts of atmospheric conditions with sufficient detail and accuracy for supporting the Navy mission in threat detection, weapons deployment, and weather safe operations. The data assimilation system will utilize all available weather data, such as Doppler radar, in situ, and remotely sensed observations. The system will run efficiently and generate a detailed analysis of the atmosphere with sufficient accuracy to predict target area weather conditions. This information can then be fed back to weapon system operators to improve detection and strike capabilities.

OBJECTIVES

The objective of this research is to build an advanced high-resolution data assimilation system for the Navy Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS®) for on-demand use in COAMPS-OS® and at the same time, investigate the impact of high-resolution data assimilation on short-term mesoscale numerical weather prediction. This data assimilation scheme will be able to analyze mesoscale and storm-scale weather by applying sophisticated analysis procedures capable of ingesting the information from Doppler radar, satellite, and other remote sensors. The primary focus of this effort will be to design a system that optimally utilizes the available weather data such as DoD Doppler radar data for initializing COAMPS.

APPROACH

The Naval Research Laboratory (NRL), through collaborations with universities, is developing a high-resolution data assimilation system. The system includes a variational approach for Doppler radial velocity data assimilation that uses the background fields provided by atmospheric predictions from COAMPS at non-synoptic times and/or analyses from the newly developed NRL Atmospheric Variational Data Assimilation System (NAVDAS) at synoptic times. The variational approach with a simplified adjoint method is used to achieve the high computational efficiency needed to assimilate high-resolution data from Doppler radars (including DoD radars on ships and at forward-deployed locations). Recently, an innovative approach has been proposed to provide the data assimilation system with flow-dependent background error covariance estimated from COAMPS ensemble forecasts with an ensemble Kalman filter (EnKF) currently under development at NRL. The assimilation time window is synchronized with COAMPS integration time steps and radar volumetric scans to enhance the coupling of the model with the data. To compliment the radar assimilation

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14. ABSTRACT

Our goal is to develop a short-term high-resolution data assimilation capability that can provide the Navy with improved analyses and forecasts of atmospheric conditions with sufficient detail and accuracy for supporting the Navy mission in threat detection, weapons deployment, and weather safe operations. The data assimilation system will utilize all available weather data, such as Doppler radar, in situ, and remotely sensed observations. The system will run efficiently and generate a detailed analysis of the atmosphere with sufficient accuracy to predict target area weather conditions. This information can then be fed back to weapon system operators to improve detection and strike capabilities.

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system, the cloud information from high-resolution geostationary satellite observations (such as the infrared and visible imagery), and surface cloud observations is also fused and assimilated to enhance the cloud analyses in the model initial fields.

WORK COMPLETED

During fiscal year 2008, several research and development efforts have been accomplished to enhance NRL capability in acquisition, processing, quality control, and assimilation of real-time DoD shipboard radar data into COAMPS. Research resulting in improved impacts of assimilated data on hazardous weather prediction was accomplished by developing new algorithms for the data assimilation system that increase the system's ability to deal with strong non-linearity at meso- and storm-scales and in estimating flow-dependent background error covariance.

The improved NRL capability in acquisition, processing, quality control and assimilation of the real-time SPS-48E shipboard radar data was a major achievement of this project in the past year. An innovative technique has been developed at NRL that compresses the raw (level-II) SPS-48E radar data significantly and allows the transfer of near real-time radar data, minimizing the operational bandwidth required, from ships to Fleet Numerical Meteorology and Oceanography Center (FNMOC) where the data will be processed and assimilated into COAMPS. Studies were also conducted to investigate the cause of some artifacts, especially the so called "ghost island", contained in the raw radar reflectivity data. The reflectivity and Doppler radial velocity data from the SPS-48E collected by the prototype Hazardous Weather Detection and Display Capability (HWDDC) during the USS PELELIU's encounter with hazardous weather near Hawaii on February 22, 2006 were also processed. The reflectivity data have been assimilated into COAMPS, which showed moderate impacts of microphysical information inside storms retrieved from radar observations on ocean storm prediction.

Another major accomplishment of this project was the development of the Ensemble Kalman Filter (EnKF) at NRL. This effort adds a new component and capability to the NRL data assimilation systems to estimate flow-dependent background error covariance from COAMPS ensembles and to provide initial conditions to the COAMPS ensemble forecasts. This is especially important in meso- and storm-scale weather predictions in which ageostrophic flows dominate and play an important role in the weather system development. The EnKF has been integrated into the COAMPS ensemble previously developed at NRL, which uses NOGAPS ensemble forecasts as lateral boundary conditions (and the initial perturbations as well at cold starts), and into the NAVDAS system to share the same observational data, data quality control procedures, and the observational data error covariance with NAVDAS and NAVDAS-AR (a 4dVar system) for COAMPS data assimilation. The system has been tested with both simulated and real observational data with interesting results. Radar data are to be added to the EnKF.

RESULTS

1. Acquisition, processing, quality control, and assimilation of SPS-48E radar data.

The high-resolution data assimilation system developed at NRL takes advantage of Navy vessels having weather radar capability (e.g., SPS-48E/G HWDDC; SPY-1 Tactical Environmental Processor or TEP). The ships in the battle fleet having this capability will have the capability to each generate a full-resolution Universal Format (UF) radar data file approximately every 5 minutes. For the purposes of radar data assimilation, three files will need to be transmitted to FNMOC in near-real-time per hour.

UF file sizes range from ~5 MB (SPS-48E) to ~13 MB (SPY-1). To minimize the load on the operational bandwidth, the UF files have to be significantly compressed before transmission, requiring a high compression rate that even the state-of-the-art data compressors cannot provide. To overcome this challenge, the archived SPS-48E UF data obtained from an at-sea experiment onboard the USS PELELIU (LHA5) in February 2006 were analyzed. By employing the divide-and-conquer approach on these UF files that separates the actual radar data from the headers (which account for about 30% of the overall UF file size) and efficiently exploiting the inherent redundancies existing in the headers, we were able to losslessly compress the headers to negligibly small sizes. A data thresholding operation was also adopted to achieve data reduction and thus larger compression on the radar data while maintaining sufficient information content to impact the model analyses and forecasts. As a final step, the open-source *bzip2* algorithms were applied to the data. Depending on the amount of precipitation echo observed throughout the SPS-48E radar area coverage and on the amount of thresholding employed, we were able to compress the UF files down to between 88 KB and 250 KB. More than 250 UF files with an average file size of about 5 MB were selected to test the data compression software. Figure 1 gives the sizes of these UF files after the compression. The average compression ratio was approximately 20:1, which is the typical compression ratio expected for future SPS-48G and SPY-1 UF data as well. The UF file compression software package will be tested for approval for ship installation by the Integrated Test Facility laboratory at the Space and Naval Warfare Systems Center (SPAWAR), San Diego, California. This research was conducted with coordinated efforts with the 6.4-Radar Data Assimilation sponsored by SPAWAR and collaboration with the Department of Electrical and Computer Engineering, University of Alabama in Huntsville.
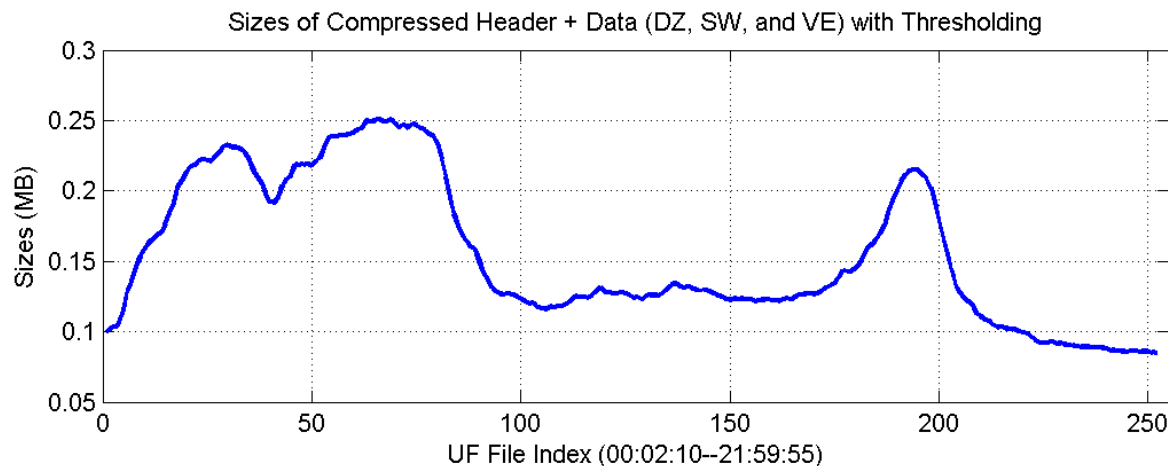

Figure 1. Sizes of the compressed SPS-48E shipboard Doppler radar
UF files (the original sizes are about 5 MB).

Quality control of shipboard radar data presents new challenges due to the moving platform. Fixed ground clutter maps are no longer useful. Furthermore, during the analyses of the SPS-48E data obtained from an at-sea experiment onboard the USS PELELIU (LHA5) near the Hawaii Islands in February 2006, artifacts, which we call "ghost islands", were found in the radar reflectivity observations. Figure 2 shows a radar PPI image of reflectivity from the SPS-48E 0.2^o elevation scan at 19:50 UTC 22 February 2006. In addition to the precipitation echoes from storms, sea clutter and the

ground clutter of the islands, a "ghost island" is also seen northeast of one of the Hawaii islands (indicated by the arrow) in figure 2. Further investigation found that these "ghost islands" contained in the reflectivity data are created by the radar beams that are reflected off the forward mast of the ship and travel toward the real islands at an angle off what the radar expects. Software has been developed to identify and remove these artifacts from the shipboard radar data.
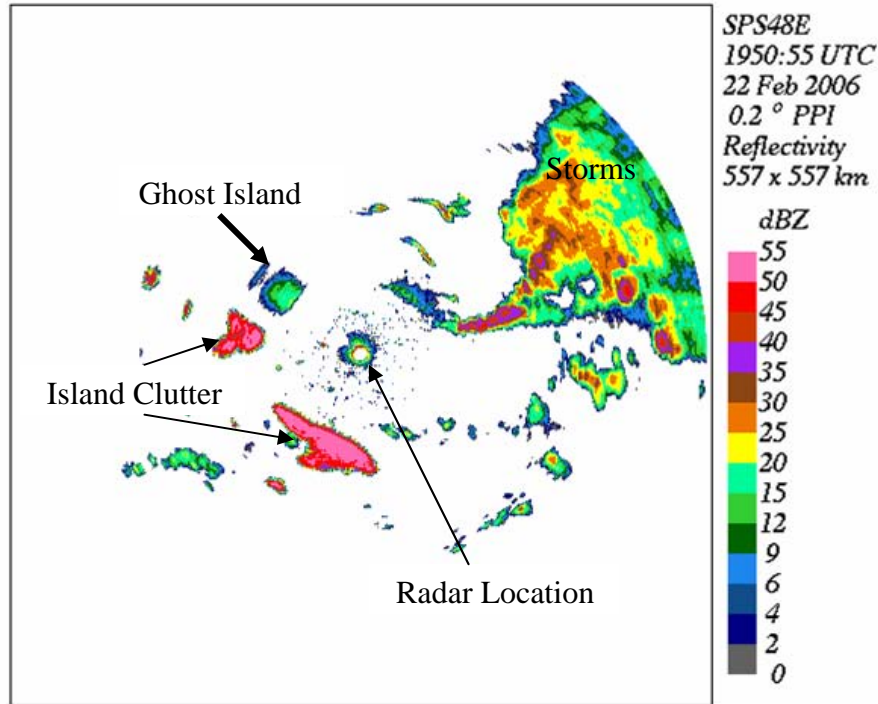

Figure 2. A SPS-48E radar PPI image of reflectivity that shows a ghost island near one of the Hawaii Islands.

Radar observations of reflectivity from the SPS-48E collected by HWDDC during the USS PELELIU's encounter with hazardous weather near Hawaii on February 22, 2006 were assimilated into COAMPS using the 3DVAR technique developed at NRL to study the impact of shipboard radar data on the forecasts of storms over oceans. Two COAMPS 12-hour forecasts were produced, one without radar data assimilation (control run) and one with radar data assimilation (experiment). Figure 3 gives the equitable threat scores of the storm prediction during the 12-hour forecast period for different storm intensity (defined by the radar reflectivity) regions. The overall scores from the radar data assimilation experiment are better than those from the control run. It is also noticed that the radar data assimilation impacts on storm prediction last up to 12 hours. However, the improvement in the storm forecast skill by the radar data assimilation is moderate. It should be pointed out that for this case, the storm size was quite large and the SPS-48E radar covered only portion of the whole storm system. Furthermore, the Doppler radial velocity data from the SPS-48E are very limited (with 3 lowest elevation scans only and the data were cut off at 50 km) and basically not useful for data assimilation. Based on our studies with the land-based WSR-88D radar observations, we expect that with Doppler radial velocity data coverage extended with the future shipboard radars (e.g., the SPS-48G), the radar data impacts on ocean storm forecasts will be significantly improved.
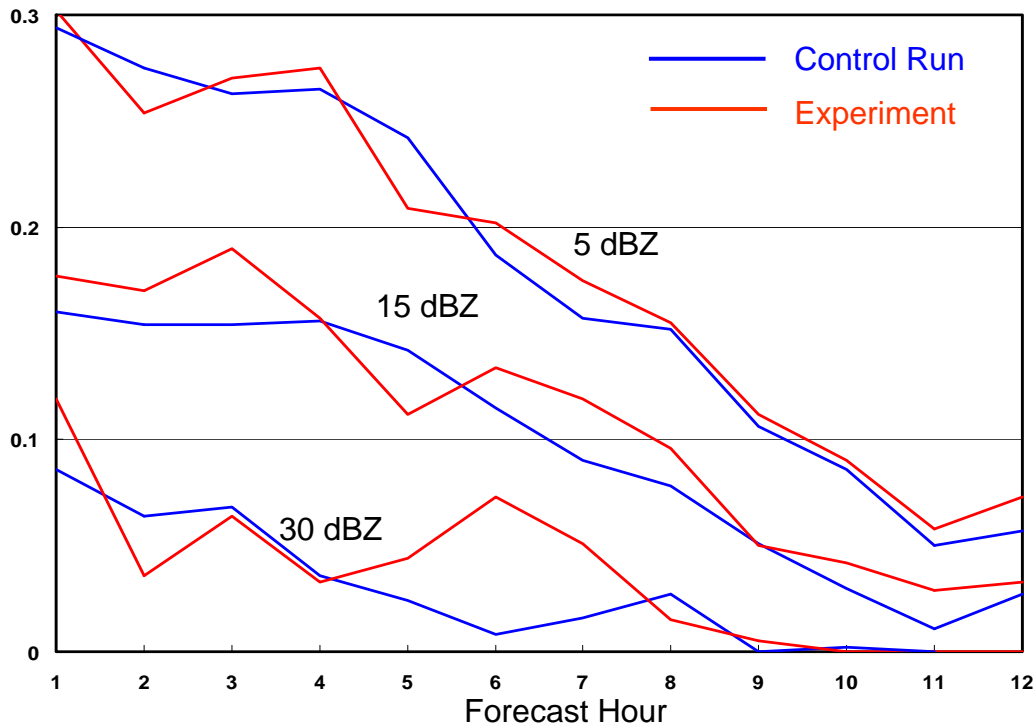
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Figure 3. Equitable threat scores of storm forecasts by COAMPS for three different storm intensity regions (defined by radar reflectivity) from the control run and the radar reflectivity data assimilation experiment. (22 February 2006 Winter Storm, Data from SPS-48E onboard the USS PELELIU).

2. Development of NRL ensemble data assimilation system

One of the disadvantages of the data assimilation system currently used for radar data assimilation is the use of static background error correlations. As an example, figure 4 gives the isotropic horizontal background error correlations of temperature and between temperature T and the v-component of the horizontal winds. These pre-defined correlation fields are relatively simple and still widely used by some 3dVar systems. However, they are based on some assumptions, which may not be true in the real atmosphere (especially near severe weather systems where the ageostrophic winds play an important role development), and do not change with the weather system evolution. The background error correlations from the EnKF, on the other hand, are dynamically calculated from the ensemble forecasts with the synoptic patterns associated with weather systems accounted for. These flow-dependent background error correlations reveal the relationships among the prognostic variables at the time when the data assimilation is performed. However, the above statement is based on the assumption that the number of ensemble forecasts is large enough to represent the uncertainties in the model forecasts. Studies have been conducted to investigate the impact of ensemble size on the estimation of background error covariance. Figure 5 shows an examples of the horizontal background error correlations of T and the cross-variable background error correlations between T and the v-component of the horizontal winds on a horizontal level near 500 hPa for a single observation of T at 500 hPa (located at the black dot in figure 5) with different numbers of ensemble sizes. Differences can be seen between the correlation fields from different ensemble sizes. The 16-member ensemble shows the

strongest correlation near the observational location but with the largest spatial variations in the correlation fields. However, all these correlations in figure 5 show similar patterns and basically the same horizontal correlation scale that looks realistic and closely related to the weather system the observation is located in. This simply implies that with a reasonable number of ensemble forecasts, the EnKF is able to produce flow-dependent background error covariance that reflects the main features of the observed weather systems at the time of data assimilation. This is actually good news for operational implementation of the ensemble data assimilation system in cases where computational resources are an issue.
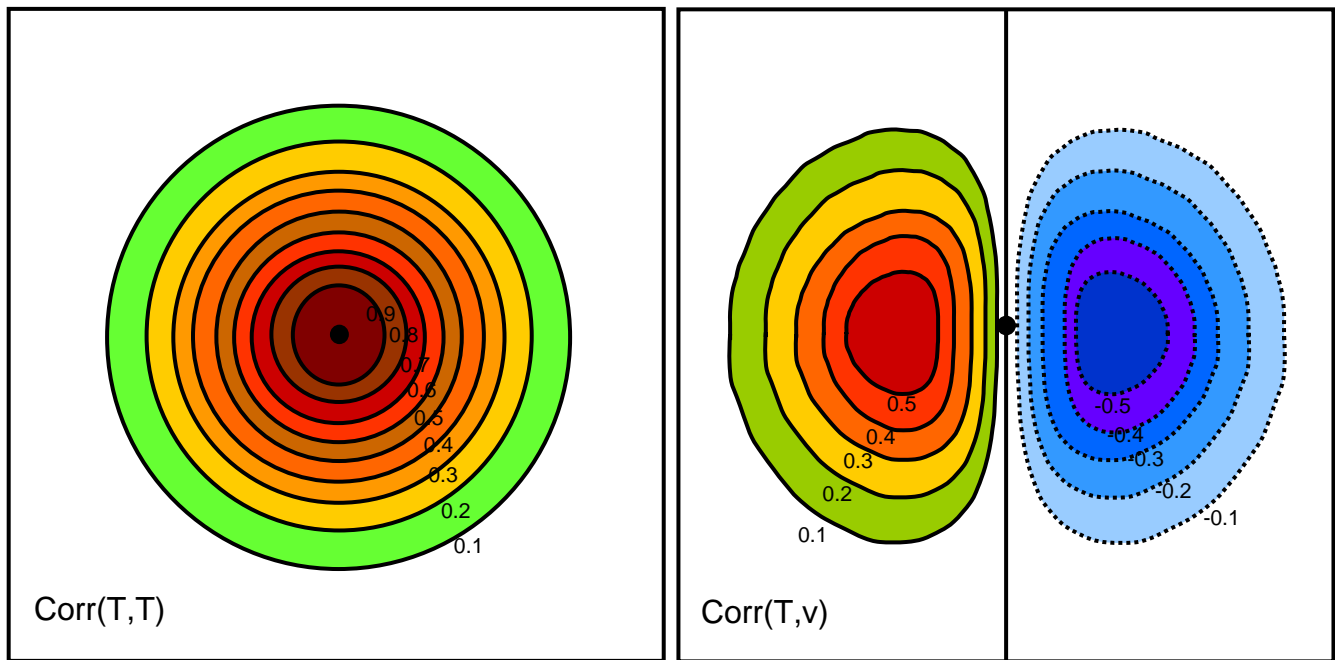

Figure 4. Isotropic horizontal background error correlations of temperature and between temperature and the v-component of the horizontal winds for a single observation of temperature (located at the black dot).

IMPACT/APPLICATIONS

The high-resolution data assimilation system developed at NRL for both conventional meteorological observations and high-resolution sensor data from radars, satellites and other remote sensors for the COAMPS model will provide the Navy with near real-time, three-dimensional cloud and wind analyses and short-term (0-48 hours) theater-scale weather forecasts in any region of interest to support the Navy's mission. The technology was demonstrated during Fleet Battle Experiment – Juliet with products providing up-to-date, detailed information to tactical decision makers about the three-dimensional atmospheric battlespace conditions. The high-resolution winds from both the data assimilation system and the COAMPS model forecast are also used to drive chemical/biological (CB) dispersion models, which are used for assessing contamination avoidance and decontamination strategies. While focusing on battlespace environmental applications, this work also establishes a scientific framework for utilizing radar-derived meteorological information in nowcasting and numerical weather prediction applications.
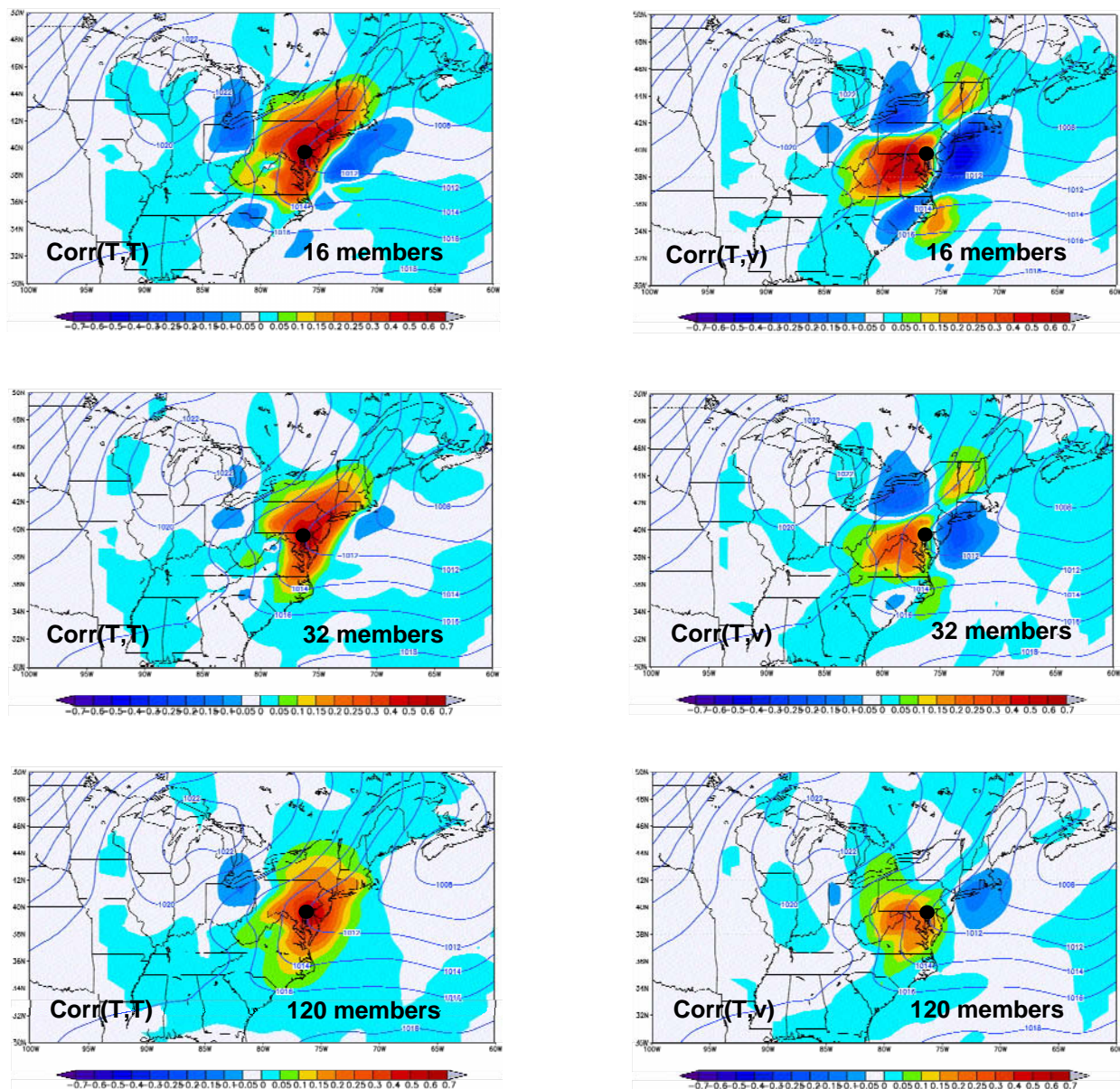
Figure 5. Horizontal background error correlations of temperature and between temperature and the v-component of horizontal winds at a horizontal level near 500 hPa for a single observation of temperature at 500 hPa estimated from COAMPS ensemble forecasts of three different ensemble sizes.

TRANSITIONS

None.

PATENTS

NRL Three-Dimensional Radar Reflectivity Mosaic System (pending).

RELATED PROJECTS

Related NRL base projects include BE-435-047, Advanced Assimilation of Non-conventional Data for Improved High-Impact Weather Prediction, and BE-435-003, Probabilistic Prediction of High Impact Weather. Other related projects include Radar Data Quality Control and Assimilation At the National Weather Radar Testbed (NWRT) (ONR, N000140410312), 6.4 Reach-Back Doppler Radar Data Assimilation (PMW 180, X2341) and 6.4 On-Scene Tactical Atmospheric Forecast Capability (PMW 180, X2342).

PUBLICATIONS

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